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Loomans, Marcel; Leeuw, Jos De; Middendorf, Gertjan; Nielsen, Peter V.

Published in:
REHVA Journal

Publication date:
2020

Document Version
Publisher's PDF, also known as Version of record

This article is based on a paper published in
TVVL Magazine 2020-05, October 2020

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MARCEL LOOMANS
Eindhoven University of Technology, Group Building Performance – Focus area IEQ and Health, Eindhoven
M.G.L.C.Loomans@tue.nl

JOS DE LEEUW
ISSO, Rotterdam
j.deleeuw@isso.nl

GERTJAN MIDDENDORF
VLA, Vereniging Leveranciers Luchttechnische Apparaten, Zoetermeer
g.middendorf@xs4all.nl

PETER V. NIELSEN
Aalborg University, Division of Architectural Engineering, Aalborg, Denmark
pvn@civil.aau.dk

Keywords: COVID-19 and recirculation: air quality, health, building level, room level, ventilation efficiency, airborne transmission

Introduction

Recirculation is an important topic in the advice to anticipate the spread of viruses in buildings and spaces [1,2]. However, the advice on recirculation also raises some questions. A generic advice cannot always be translated one-to-one in a specific situation. In this short article we would like to explain the backgrounds of the proposed advices (as found in, e.g. [1] and [2]) in more detail. With this we hope that a (large) part of the questions that may still remain can be answered and we also hope that this will make it easier to consider one's own situation and to take the possible desired measures.

First the definition: Recirculation is the reintroduction of exhaust air into the room or building. This recirculated air is then often first mixed with (clean) outside air, the ventilation component (see **Figure 1**). Normally, through a high recirculation rate, the aim is to provide heat or cold via the supply air, without the need for a high ventilation rate. This avoids the need to condition a large amount of (ventilation) outside air. It results in energy savings, often in combination with

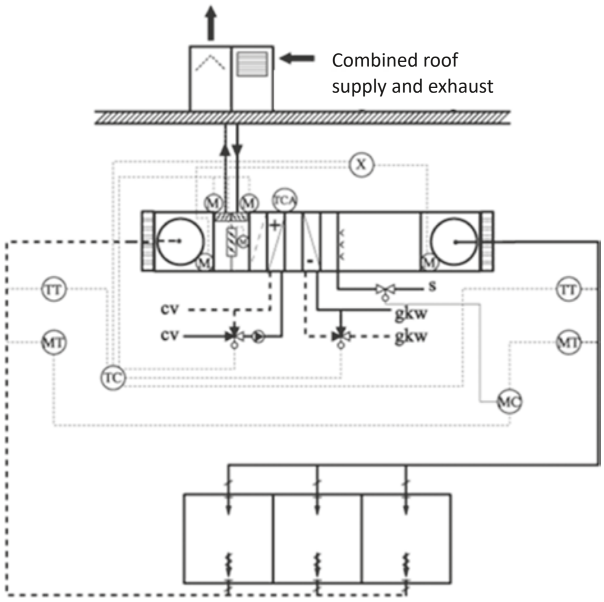


Figure 1. Example of a recirculating solution. Figure taken and translated from [3].

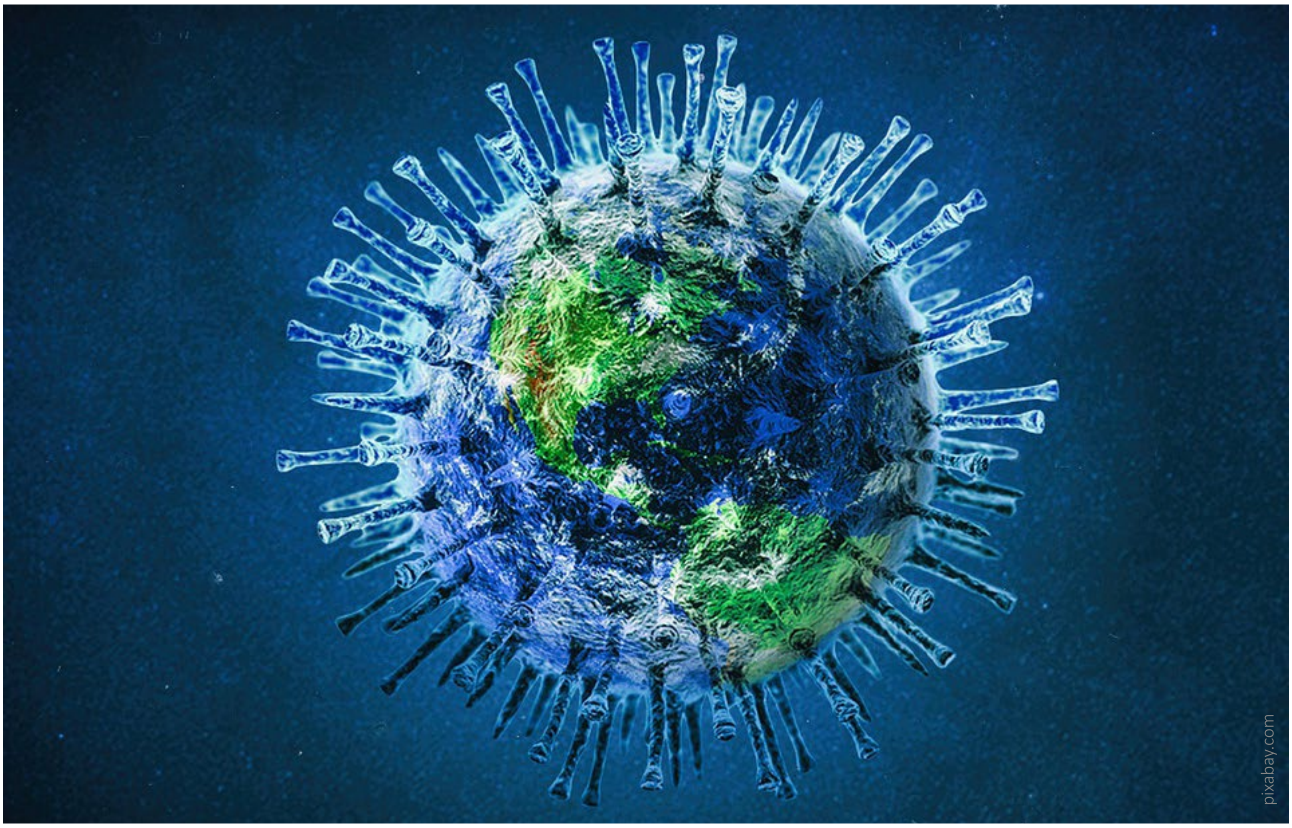
the possibility of limiting the capacity of the heating and/or cooling system. In new buildings heat recovery is a legal requirement since 2014 (EU 1253 [4]) in case of balanced ventilation. However, the desired heat transfer can be achieved without the need for recirculation, for example by means of a twin-coil system, crossflow heat exchanger or rotary heat exchanger. In practice, however, there are still many often somewhat older buildings, with mechanical supply and return, where recirculation is used as part of the air treatment system. Often it is not possible to switch off recirculation completely without creating capacity problems with regard to heating and cooling.

Where the energetic and capacity reasons regarding heating and cooling capacity are clear, the use of recirculation is less logical from a health point of view. After all, 'polluted' air is brought back into the building. In principle, this air can also end up in places/spaces where there are no sources of pollution and thus lead to health or other complaints elsewhere in the building. The contamination can be broadly defined, CO_2, odors, particulate matter, but also germs. By only supplying outside air, i.e. ventilation, you can easily prevent these contaminants from being reintroduced into the building.

This is the underlying explanation for the advice not to use recirculation. However, we can still make a distinction. The explanation as described above focuses on building level. There is also a possibility to recirculate at room level. This is often done using secondary air circulation systems such as a fan-coil unit, split-unit or induction system. In the description below we will deal with both levels separately.

Recirculation at building level

At the building level, the use of recirculation is undesirable in the context of health in general, when talking about local sources that can affect a person's health. In the current situation it is the SARS-CoV-2 virus and therefore a precaution against COVID-19. Through recirculation at building level, it is possible that viruses produced in one room are spread throughout the building. The concentration is then of course reduced. Although at the moment the (long-range [5]) risk of infection via airborne transmission is not considered high, it is desirable to prevent this from happening from a precautionary point of view. A recent study [6], although not yet peer-reviewed, shows that the virus can be found on filters in the air handling unit when recirculation is used and therefore the risk is not a hypothetical assumption. In this case, only the RNA has been detected and not tested for viability. Not using recirculation prevents this situation from occurring. In principle, the ventilation level, i.e. the



fresh air supply, should not have to be adjusted for this if it is already sufficient. If the ventilation level is assessed as insufficient, you should increase this level, but this is independent of not using recirculation at building level. From an air treatment point of view, there could be capacity limitations at high (summer) and low (winter) outdoor temperatures. If more ventilation can be provided, this is only positive. If this is not the case, it is necessary to consider to what extent the thermal comfort is affected by the transition to an air-conditioned situation based on outdoor air solely.

With regard to particles (viruses are transported via particles/aerosols) there is the possibility to filter air. In this way you could clean the recirculated air. Often there will be some degree of filtration present in a recirculation system. However, these filters, and as a result the total air treatment system, are normally not designed to effectively remove the small (<1–2.5 micron) particles [6]. It is precisely these particles that play a role in the airborne transmission route because they can float for a long time. Placing better filters is an option, but will often not be possible due to the higher pressures in the existing air handling unit that will then be required. For microbiological contamination, if done properly, there is also the possibility to remove them by means of ultraviolet light (UVGI - ultraviolet germicidal irradiation) or ionization.

Considering the above, it is best not to use recirculation at the building level. Where it is impossible to prevent this completely due to capacity problems, it should be minimized as much as possible. Improvement of filters should be considered then, and the ventilation level should be set as high as possible. The latter to make dilution as large as possible. Specific situations (multiple infections, long-term presence, sensitive groups, e.g. nursing homes) provide emphatic reasons to avoid recirculation.

Recirculation at room level

At room level, different types of delivery systems are used to bring air into the room and to condition air. Sometimes this is combined. Especially when it concerns systems that also provide for (part of) the ventilation of the room, these should not be switched off. An induction unit is a typical example of such a system. Such a unit also provides the fresh air supply (ventilation) of the room. Ventilation is one of the most important components in the strategy to reduce the (long-range) airborne risk. The more ventilation with fresh outside air, the better. Also, many fan-coil units will have a fresh air (ventilation) component. Again, the advice is to keep these types of systems running.

Where a system does not contribute to ventilation, the advice becomes more difficult. A split-unit is a typical example of a system at room level that often does not contribute to the ventilation of a room. However, it can be essential in the conditioning of the room to achieve pleasant thermal conditions. In the recent period, the advice from the RIVM (Dutch National Institute for Public Health and the Environment), REHVA, [2], etc. on whether or not to use such a unit has been somewhat diffuse. In principle, the advice is not to use such a unit. The starting point for this advice at room level is that we want to prevent the direct transmission of the virus through airflow between people. The problem here is that this advice is easily stated in a generic way, but that the interpretation is very case-specific and often difficult to assess.

Transmission by airflow between persons can occur when a (direct) airflow between persons in a room can occur. In practice, supply grilles and systems such as a split unit will be designed and placed in such a way that a mixing situation arises in a room. Whether or not the split-unit is switched on will then not change much to the mixing situation. This means that it is not to be expected that this will result in a stable airflow between two people. In certain cases, however, it is possible that by turning on the unit, circulation flows (vortices) will be created in the room, which may develop into such a flow of air between people. The case in the restaurant in

China [7] shows the possibility of this. This concerned a unit on the wall that created a standing room air recirculation flow via the ceiling. It should be noted that in this example, the ventilation level in the restaurant was very low. With respect to COVID-19, for a ceiling unit the direction of flow could be set parallel to the ceiling, preferably in all directions, so that mixing is optimized and no recirculation flow can develop similar to the situation as sketched for the restaurant in China [8,9]. It must be stressed that the main point of departure is always a well-functioning ventilation system and sufficient ventilation of the room.

Often it will not be easy to gain insight into the air flow that is created in a room. Smoke for visualization is a useful tool, but it is better to leave the assessment to an expert such as a building services consultant. Another important note is that if the system remains on, the ventilation must remain in order in all cases. With a working system, cooling will probably give the impression that the air has to be ventilated a little less, because the air can also be assessed as 'fresh' from an air quality point of view [10]. This is not desirable. Ventilation in this case, and in fact always, is first and foremost intended to keep the air quality high.

Ventilation principles

In addition to the importance of sufficient ventilation, for the sake of completeness we would also like to briefly discuss ventilation efficiency for room ventilation solutions. There are two main principles: mixing ventilation and displacement ventilation. In **Figure 2**, the principles are visualized schematically.

In principle, displacement ventilation is a more efficient form of ventilation. This means that with the same amount of air contaminants are removed more efficiently, so that their concentration in the room, in the breathing zone, is lower.

The interesting point, however, is that for the issue of aerosols this does not necessarily has to be the case. This is presented in a study by Nielsen et al. [12] in which they compare the inhaled concentration with the exhaust concentration. **Figure 3** gives a summary of some examples in which de inhaled concentration is compared to the concentration at the exhaust. In this case the persons ('source', 'receiver') are positioned 0.35 m apart from each other.

Figure 3 shows that in this case displacement ventilation (C_{max}/ C_R = 4.0–7.3; C_R: exhaust concentration of contamination, C_{max}: inhaled concentration of the 'receiver') performs less well than a mixing ventilation solution (C_{max}/ C_R = 1.7–2.1). The explanation for this is that, at a relatively short distance, the breath of the 'source' person can break through the boundary layer of the 'receiving' person. Displacement ventilation appears to be more sensitive to this than a mixing

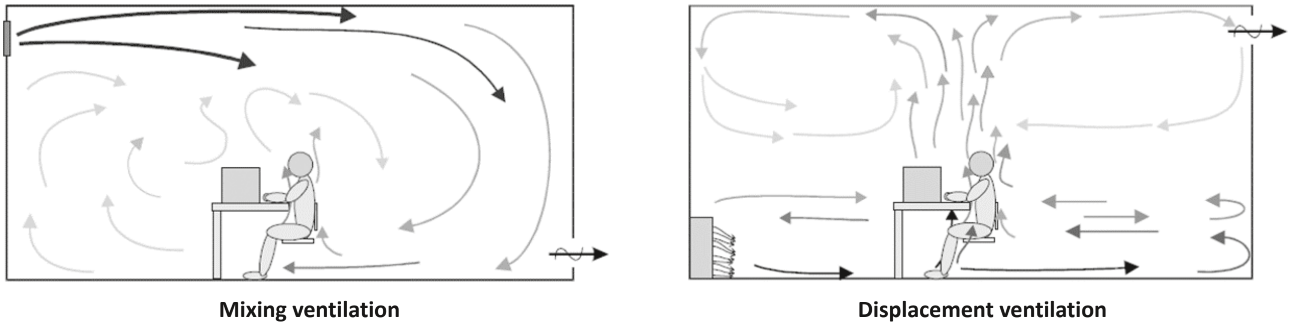


Figure 2. Schematic representation of the principle of mixing ventilation and displacement ventilation. [11]

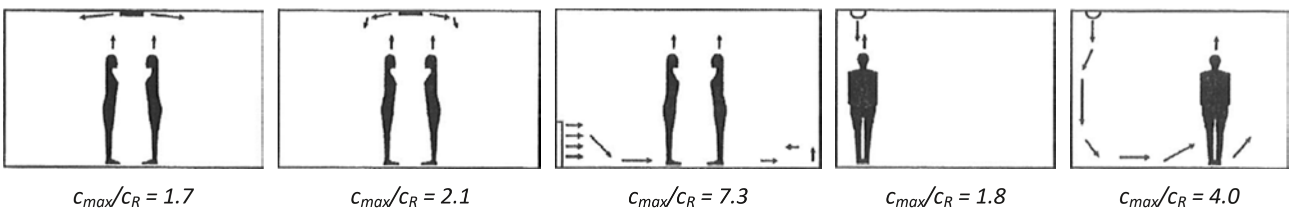


Figure 3. Comparison of different flow situations in a room expressed through the ratio of the exhaust concentration of pollution (C_R) to the inhaled concentration of the 'receiver' (C_{max}) with the emission of particles (pollution) by the other person in the room [13] (based on [12]).

situation. This is a problem at a short distance, but also at a larger distance displacement ventilation can perform less well in such a situation. The exhaled air can become trapped in a stratified, calm, layer that is characteristic for displacement ventilation. As a result, the particles can stay there longer and spread further [14]. In a mixing situation, these particles are in that case better diluted and removed.

In conclusion

With the current experiences, the importance of having a good ventilation has been shown once more. Recirculation no longer belongs in new buildings. There are good alternatives to make heat recovery possible without having to mix air. At room level, we need to be aware that decentralized systems contribute to the conditioning of the space, but that here too ventilation must remain leading. In these times of COVID-19, but also for the future, efficient ventilation is important, but in the spread of germs between people, other performance indicators for ventilation are also important. It is good to recognize them and to take them into account now, but certainly also in the future. ■

Acknowledgement

This article is (nearly) a directly translated version of the article that was prepared for TVVL Magazine (Nr.5 – October). For the initial translation DeepL has been applied.

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